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Mind the body: how embodied cognition matters in manufacturing

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Abstract

Embodied cognition can provide human factors and applied ergonomics practitioners with better embodied cognition design principles. This paper investigates and analyzes observational video-recorded data from an experiment that simulated a manufacturing environment. The operator was interrupted during a primary assembly task via a handheld computing device which delivered different classes of notifications. The focus is on the embodied aspect of notifications in an active environment, and why one class of notifications called mediated notifications failed at a specific point previously thought to be suitable. Guidelines for analyzing tasks from an embodied cognition perspective that complements and expands traditional human factors and applied ergonomics approaches were developed and are included.

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Keywords:

1. Introduction

The interest in cognitive aspects of human performance has dramatically increased in recent years within manufacturing, something that may have great impact on production process in manufacturing. The embodied cognition approach to the human mind can provide human factors and applied ergonomics with novel ideas about how tasks are done and how the human mind works. It has been pointed out by several researchers that the physical body has a fundamental role and relevance for our interactions with the social and material world (e.g. [1, 2, 3, 4, 5 6, 7]). Consequently, the way we interact with the resources in our environment affects and changes the ways in we

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perceive, act and think. Hence, we do not just think with our brains but through our bodily interactions, and there are times we actually ‘think’ with and through our hands and with accompanying tools (e.g. [4, 8, 9, 10]).

The embodied cognition approach offers complementary perspectives to the area of physical ergonomics, which has been successfully investigated for a long time, to also include cognitive aspects of embodied actions may offer significant insights and contributions to the fields of human factors and applied ergonomics. Generally speaking, in the past, physical ergonomics had to worry about fitting technology to human bodies, but today’s technology must also fit humans from an embodied cognition perspective. It should be noted, however, that the idea of putting the mind and body together, providing an integration of physical and cognitive dimensions of task operations, has been addressed lately in ergonomics [10]. At a first glance, this human-systems approach seems to take a embodied cognition approach, but taking a closer look, we argue that this is just ‘old wine in new bottles’, namely putting an embodied icing on the traditional “mental gymnastics” [2] cake of internal information-processing. We want to highlight that addressing the role and relevance of the body-brain-environment system, characterizing that cognition is for action, may be of major practical importance in manufacturing where operators still perform many manual tasks.

This paper investigates and analyzes some observational video-recorded data from an experiment that simulated a manufacturing environment. The operator was interrupted in the primary assembly task at different intervals, via a handheld computing device, that delivered different kinds of notifications (notifications are, in the context of this paper, a way of presenting information or data to a user to interrupt the user, and a notification system is the underlying apparatus that transfers and presents notifications [11]) . The focus here is on the embodied interaction aspect of an assembly task that was interrupted by a mediated coordination method. The primary guiding question for our analysis was - why did subjects miss notifications at a particular point in the assembly task when faced with mediated interruptions?

The obtained finding from the observational study has been analyzed with influence from Wilson and Golonka’s [7] four key questions to fully engage with the implications of embodiment, and then generalized to some design implications for handling the effects of embodiment in manufacturing.

2. Background

2.1. Interruptions research

An interruption is characterized as any event that breaks a person’s attention from their current activity (primary task) and either requests or forces the user to focus on a new task (interruption task). Corraggio [12], for example, provides the following definition: “an interruption is an externally generated, randomly occurring, discrete event that breaks continuity of cognitive focus on a primary task" (p.19). Interruptions can cause increases in errors on the primary task and induce errors on the interruption task, but McFarlane and Latorella [13] argue that this can be minimized through taking into consideration the requirements of the person, the primary task, and the interruption task.

Despite the wide academic literature in fields such as cognitive science, aviation, and human-technology interaction concerning interruptions research, the synthesis and application of these theories in industrial domains like manufacturing, has not yet reached its full potential. Interruptions have a high cost for the person being interrupted in many cases. Switching between tasks, even when done in a controlled manner, incurs a cost in terms of time and performance on both tasks [14]. The performance loss can be mitigated through preparing for the task switching, as well as through having easy ways of “entering” the new task. The same goes when switching back to the primary task; if the task can be left in such a state that it can be easily resumed and/or if the primary task is set up in a manner that allows easy resuming of the task then the performance cost of task switching is greatly reduced [15].

There are several ways proposed for managing interruptions. McFarlane [15], for example, suggest a taxonomy of interruption coordination methods that focuses on two main factors: the type/priority of the task being interrupted, and the type/priority of interruptions. McFarlane [15] presents four forms of interruption coordination methods, and these are referred to as; (1) negotiated, (2) mediated, (3) scheduled and (4) immediate interruption coordination methods. Due to space restrictions, we focus mainly on mediated interruptions, which is described as having a system acting as a secretary that judges whether interruptions are appropriate, but also the most complicated to implement in a notification system.

McFarlane [15] and McFarlane and Latorella [13] find the nature of the primary task to be of paramount importance for selecting what type of interruption coordination method should be used. Research exists on notification systems that respond to the context and user activity and shows notifications at natural breakpoints in a person's activity [16] instead of just popping up notifications at any time incurs a lower cost in both errors and switching times. This kind of system needs to use automatic sensing of task breakpoints. Bailey and Konstan [17] found that interruptions that are presented at more natural breakpoints between tasks affect users' anxiety and annoyance significantly less than when interrupted in the middle of a task, so that should be the goal, but when that is not possible then directing interruptions towards the end of a sub-task is better, and best of all if it is possible to present interruptions between well-defined and clear tasks [18].

2.2. Embodied cognition

The enactive and embodied view of human cognition starts with the idea that humans are action oriented; i.e. cognition is primarily for action and anticipation of action. Our ability to make sense of the world comes from an active and pragmatic engagement with the world, along with our capacity to interact with other humans. A central issue here is how the human body, not only the brain, is the source to cognition, given that our bodies and their perceptually guided movements and actions in the world do much of the effort necessary to reach our goals (e.g. [2, 3, 4, 5, 6, 7, 19]). This is contrary to traditional ideas of how the mind works, characterized by the so-called computer metaphor of mind, where cognition is considered as symbol manipulation of internal mental representations, designed to produce an outcome/behavior on demand, viewing cognition a kind of "mental gymnastics", using Chemero's [2] terms, where the body is reduced to an input and output device. It should be noted, however, that many traditional cognitive scientists disregard the embodied cognition approach completely, or interpret it more in line with how the body biases internal cognitive processes. The stance put forward in this paper is more radical, focusing on how brain-body-environment system works in cognition, which offers a radical shift in explaining and studying cognition. More specifically, it is the stance to study and characterize how cognition "emerges from real time interplay of task-specific resources distributed across the brain, body and environment, coupled together via our perceptual systems ([7] p. 1). Broadly speaking, taking the radical embodied cognition perspective, some issues that were totally neglected earlier, or placed in the background when describing and analyzing cognitive behavior as mental gymnastics, will now be of crucial importance and placed in the foreground. In what follows, we present some characteristics of how to describe cognition from an embodied stance that may be of relevance for assembly in manufacturing.

Wilson [19], for example, claims that "cognition is situated", given that cognition takes place in the context of a real world environment, involving perception-action couplings running online. Clark [20] also discusses the situated nature of human cognition, arguing that "human reason is, we may say, disengaged but not disembodied" (p. 236). He argues there is no sharp line between so-called online versus offline cognition, given that both processes are running in parallel. He introduces the concept of surrogate situatedness in order to explain how humans create and use human-built structures in order to transform the space of higher-level cognition through offline cognition. Hence, he stresses that humans actively create restricted artificial environments that allow us to deploy basic perception-action-reason routines in the absence of their proper objects, which he dubs "surrogate situations" that is used in offline cognition [20]. Some examples provided by Clark are the use of a dotted line, a drawing, and when the target situation is the as yet non-existing door on a sketch, in which the surrogate situation is the context provided by the drawing. These surrogate situations both allow human cognition to be disengaged while at the same time offering a concrete place in which to organize action-perception couplings of an essentially real world-like kind of interaction. Surrogate situations provide a midpoint in the evolutionary past of human development, between completely offline imaginative modes of cognition and the more time-constrained real-world interactions 'here and now' as in online cognition [20].

Moreover, Wilson [19] claims that online "cognition is time-pressured", stressing the fact that a living organism has to cope with changing situations 'here and now', dealing with time-pressure. Research conducted on autonomous agents has emphasized the significance of time-pressure as a constraint for shaping behavior [5]. Despite the fact that these real-time activities in themselves cannot be considered particularly ‘intelligent’, she suggests that more advanced structures of cognition can be grounded in successive layers of environmental real-time interactions. Therefore, the agent (human or artificial) has to generate cheap and efficient tricks to handle the problem, in order to avoid a cognitive ‘break down’ or decreased cognitive performance [5]. Wilson’s claim that cognition is time-pressured does not mean that all cognitive activity in general is performed in the state of “being in a hurry”, but she emphasizes the great importance of sensorimotor co-ordinations in time-locked activities, such as object manipulation, and other manual skills. Furthermore, “the use of off-loading cognitive work to the environment” is stressed, as a way of handling the demands of real-time (online) cognition. Wilson [19] notes that although humans mostly run their cognitive processes ‘offline’, there are still situations that must be carried out in situ. Consequently, we have to consider our cognitive limitations when acting in real time and one strategy of reducing the cognitive burden is the use of so-called epistemic actions [21]. These actions are used to alter the surrounding environment in order to ease the cognitive work to be done. An example of using epistemic actions can be found in Kirsh and Maglio’s [21] study of the computer game Tetris. The goal when playing Tetris is to fit geometrical falling blocks as neatly as possible into the bottom row, which contains previously dropped blocks. Furthermore, the player can rotate the blocks during the fall in order to obtain an optimal fit. Kirsh and Maglio [21] pointed out that the players actually used real rotation movements to simplify the task, rather than mentally representing a solution and then executing it. Hence, humans may ‘think’ faster with the hands, than the brain [1].

Additionally, the claim that “cognition is for action”, stresses the role of the mind to guide action. Wilson [19] argues that perception and memory have to be considered from a situation-appropriate perspective. For instance, Wilson notes that empirical work in visual perception suggests the purpose of the visual system is not to construct an internal representation of the outside world. Instead, it has been argued that some sorts of visual input directly prime motor activity, without the need for an intervening ‘higher’ cognitive process to guide action [5]. In the case of memory, Wilson addresses the claim that the traditional approach to memory as a ‘storage’, should be replaced by the view of memory as “perceptuomotor patterns”, characterizing short-term memory as the undertaking of specific action skills. Finally, “offline cognition is body-based”, meaning that the use of surrogate situations has advanced a step further, by pushing this embodied activity inward, allowing only the priming of the motor action, but no overt motion actually takes place, that is, offline cognition [3, 4, 19]. Hence, this sort of cognitive strategy may open up for new explanations of how ‘offline’ embodied cognition functions, since it has been claimed many cognitive processes indeed utilize sensorimotor functions in this ‘hidden’ way. This means that structures that were initially evolved for perception and action ‘online’, seem to be able to run ‘offline’, supporting higher-level cognitive abilities [19, 20].

3. Method and performance

The data used here was part of the data gathering in a larger experiment that tested the four interruption coordination methods proposed by McFarlane and Latorella [13] in a simulated manufacturing environment. The experiment consisted of an assembly and an interruption task. The assembly task involved mounting two front wheels onto a pedal car, with the small extra complication that each car required a specific setup of tire hardness and each wheel had specific markings denoting hardness. The interruption task involved subjects receiving a message onto a mobile device asking them to look up information on a stationary computer and send a specified message based on the received message and the information from the stationary computer. 24 subjects participated, and each subjects performed each of the six conditions once. These conditions consisted of the four interruption coordination methods [13], one control condition to test performance on the assembly (primary) task, and one control condition to test the performance on the interruption task.

During their whole performance, audio-recorded sound/noise from a real manufacturing facility was played back in the lab. Quantitative and qualitative data were collected via computer systems and video-recordings. Some pre-test and post-test questionnaires were also used to gather data. The notifications for alerting subjects that a message was awaiting response were auditory and tactile (vibration). These notifications had some different settings based on interruption coordination method used (for immediate interruptions it were load and intense signals, as a kind of alarm, whereas in mediated interruptions it was like an ordinary cell phone signal).

Here is an example of how a single assembly and interruption task was performed: Subject started assembly, looked at the note on the back of the pedal car for which wheels were required, retrieved the correct hardness for the left wheel, went to the mounting position, mounted wheel on axle, subject received an interruption message, looked at mobile device and read the message “please send error code for material shortage to X.X.”, walked over to a stationary computer, performed the task, sent the error code message, cleared information on the mobile device, then walked back to the assembly station, retrieved washer and bolt, threaded washer and bolt on the axle and hand tightened, then tightened bolt using a cordless drill. Subject then checked the note specifying wheel hardness again, retrieved the correct right wheel, and then repeated the same procedure on the other side of the pedal car, and when finalized, pushed whole assembly unit to the next assembly station (see Figure 1).

Figure 1. (left) Mounting a wheel on the axle; (centre) threading bolt and washer on the axle; (right) tightness using a cordless drill.

Mediated interruptions were a special case in that the notifications should be sent at appropriate times, which meant that pre-selected interruptions points were created based on the primary task and the notification was then sent at the next pre-selected interruption point after the random timer sent its signal. The pre-selected interruption points were after the subject finished mounting each wheel, which means that one interruption point was after completing mounting one wheel, while the second interruption point was after completing the whole assembly of that car. The random time signal was used for reference in the immediate condition and messages were triggered at the nearest pre-selected interruption point after the random time signal.

4. Findings: Analysis and results

Observing subjects’ actions in situ and through analysis of the video recordings resulted in the identification of a surprising finding during mediated interruptions (wherein interruptions points were pre-selected by the first author). Notifications sent after mounting of the first wheel, but before starting the assembly of the second wheel, were repeatedly missed by multiple subjects. Moreover, notifications sent after the completion of the whole car assembly (both wheels) were not missed by subjects at all. A similar finding was not observed by McFarlane and Latorella [13], which is likely due to the differences in research approach and experimental design, given that they used an artificial task that tightly controlled the interruptions and switching between tasks, but the tasks in the presented experiment were designed to allow subjects much more flexibility in exactly when to switch between tasks and how to prioritize tasks by themselves without experimenter intervention. The primary guiding question for the analysis was - why did subjects miss notifications at a particular point in the assembly task when faced with mediated interruptions?

In order to answer this guiding question, we took an embodied outlook, and were inspired by Wilson and Golonka’s [7] proposed four key questions in order to fully engage with the implications of embodiment. What is the task to be solved? What are the resources that the operator has to access in order to solve the task? How can these resources be assembled so as to solve the task? Does the operator, in fact, assemble and use these resources? Instead of explaining “why a given behavior have the form that it does” in terms of traditional cognitive science ideas and concepts, we replaced it with concepts of embodiment, i.e. bodies that are perceptually coupled with its environment.

The standard explanation of the mounting task goes roughly as follows. The overarching goal is to assemble the pedal car, which consists of several tasks requiring different kinds of sub-tasks, such as selecting and mounting the two wheels. The mounting task involves so many different motoric outputs on top of each other, and the time it takes for the sensory inputs to be translated to a 'symbolic code' in which the planning (or cognition in general) takes place and then decoding the outcome back into another format for motor response, takes a vast amount of time and requires too many resources [1, 2, 7]. Consequently, the computer metaphor for mind hinders rapid and demanding real-time interactions, since the operator does not have enough time to update the internal representation as a result of the manual complexity of the task and the time-pressure. In order words, the information-processing will fall outside the limitations of the cognitive abilities of attention and short-term memory, resulting in a 'break down' or decreased cognitive performance, i.e. not noticing the notification.

However, the embodied solution offers another explanation, arguing that the traditional solution above hinders rapid and real-time time demanding manual interactions, and instead the operator has to use cheap and efficient resources to handle the problem, i.e. the available kinematic information, the dynamics of embodiment (of perceptual-action couplings), and the "cognitive space" of manually mounting the wheels, as being characterized as the whole brain-body-tool-environment system [7, 8, 9]. The major resource here is the *handedness*, i. e .from an embodied cognition perspective of the human's manual hand, and it has been argues that the hand is the organ of the mind [9]. Results from neurocognitive experiments demonstrate that the hand occupies a unique role in "determining a participant's ability to detect, discriminate, or pay attention to visual or somatosensory stimuli", (Holmes, cited in [9] p. 282). It is pointed out by Holmes that most of these experiments have only studied the hand in passive situations, not considering the primary function of handedness, i.e. action-centred attention. Holmes argues that one of the most basic and evolutionary function of handedness is the action and desired-directed movements towards target objects. This handedness consists of a repertoire of appropriate grasps for manipulating objects and tools, and this repertoire is adapted according to contextual demands. It is argued that manipulating objects and using tools partly is to make changes in the environment, but also partly to manipulating the object (and using tools) to help create further opportunities for action in the environment. In other words, manipulating objects and using tools, such as in the actual assembly in the task, is an interplay between seeking a desired goal and managing the affordances/cues arising from alterations in the object (e.g. bolts, washers) in the environment (resulting from the ongoing assembly task).

This interplay may include kinetic energy into detailed hands motions and grasps, given that the operator has to appreciate how much energy and force is needed in order to appropriately threading and tighten the bolt and washer on the axle, initially only manually and then with the use of the cordless drill. The brain-body-hand-environment system as a whole can be said to be emergent, shaping and constraining the assembly activity, given that the layout of the objects in the environment as well as in your hands when anticipating the assembly task, represents 'here and now' the anticipation of actions needed to mount the wheels. In sum, the deliberately and ongoing choices made by selecting the upcoming movements with the objects, becomes a part of structuring the workplace as a kind of "cognitive space" well as the doing the subtasks in arranging the mounting *is* a form of cognition [8].

Indeed, we stress that assembly, in the form of problem solving, becomes a "matter of thinking" as the cognitive space changes as a result of the actions done, and cognition is the process to enact appropriate manual actions and anticipates the following manual actions, and a means of acting upon the cognitive space to bring fourth new opportunities for action. The assembling of the wheel could be described as real-time interplay of task specific resources, as a kind of distributed perception-action-reason (integrated across several sense modalities) in time-locked activities. Subsequently, we stress that much of skilled tool use and assembly is anticipatory, and that the expert's skill comes from the ability to control their activity with sufficient spare capacity to cope with future demands and to respond to the changing circumstances in which they are acting to effect changes in the objects being worked on, i.e. the "cognitive space" in which subsequent decisions are made [8].

Hence, this is an elaboration of the body's role and relevance in assembly, being one of the most prominent and influential aspects, when characterizing that cognition is for action and anticipation of action. The operator is fully absorbed in this online handedness way of acting, for we as humans are evolutionary developed to use our hands for action, and do not respond to the artificial sound of the notification, given that short-term memory is absorbed with the undertaking of the specific actions skills of handedness in mounting the wheel. There is no natural breakpoint for receiving a notification at this moment, given that the "cognitive space" offered 'here and now' has its natural breakpoint when both wheels are mounted, it is not until then that the available resources offered will be lacking for smoothly continuing the anticipated actions.

To conclude, it becomes apparent from the analysis and results that interruptions should be avoided during this identified point of the tasks unless the interruption has an extremely high priority and uses a strong and persistent, as well as highly disruptive, notification signal.

Summing up, this means that the relationship within the human-environment-object-tool system not only affords different actions, but also *shapes* cognition. The task to mount the wheels is performed online, time-limited, and shaped and constrained by the execution of the involved assembly's handedness. From an embodied perspective, the main goal of cognition is to support action in a situation-appropriate manner as possible. For that reason, it is not necessary to construct an inner representation (mental gymnastics) of the environment, it is only sufficient to act upon the appearance "since the world is its best model", paraphrasing embodied robots researcher Rodney Brooks [1], there is no need for extra planning since the operator is acting here and now, and hence "mental gymnastics is not a parsimonious explanation of the behavior.

5. Implications for design

The empirically obtained results showed a problem in a place that experiments using artificial tasks did not predict. Furthermore, the findings of the analysis suggest that looking separately at actions and cognition is likely to miss problems due to the cognitive aspects of actions and leave designers with problems finding answers as to why their design fails in specific conditions. The main implication of this is that a new approach is needed, and that goes deeper than simply making a new method for analysis as a new core approach is required. This involves a fully new embodied approach to human factors and applied ergonomics that not only unifies physical ergonomics and standard cognitive ergonomics but also incorporates the newer approaches to cognition that have been explored in cognitive science and have been discussed in this work. Guidelines were developed for using such an embodied approach for the analysis of systems.

These guidelines involve:

- Analyzing all aspects of an action from the user's perspective. That includes the goal and intention of the user, over-arching tasks, sub-tasks, physical actions, and the cognitive work behind each of those goals, tasks, and actions.
- Including in the analysis the "in-between" areas, i.e. the time spent switching between goals, tasks, sub-tasks, and actions.
- Including the environment (both social and material) as a resource in the analysis and examining how the user interacts with all aspects of the environment.
- Identifying on-line and off-line components of goals, tasks, and actions, and recognizing the strengths and limitations of each.
- Understanding that any actions featuring on-line cognitive processes will be prioritized above actions featuring off-line cognitive processes.
- Creating cognitive spaces for both the primary task and the interruption task that support each part of the task, keeping in mind the on-line and off-line cognitive aspects and the different requirements of each.

6. Concluding remarks

The guiding question for this study was - why did subjects miss notifications at a particular point in the assembly task when faced with mediated interruptions? The observed effect challenged our interpretation when initially observed, but taking an enacted and embodied cognition perspective provided us with relevant descriptions and explanations. By more thoroughly considering the implications of embodiment, particularly the resources of the embodied hand's handedness, the available resources in the "cognitive space", and how these were intertwined in the mounting of the wheels, it then becomes easier to see a possible reason for the observed way of acting, i.e. cognition is for action and anticipation of action. The embodied cognition approach offers complementary perspectives to the area of physical ergonomics, but differs in how it views the role and relevance of the body in cognition.

We want to highlight that addressing the role and relevance of the body-brain-environment system, characterizing that cognition is for action, may be of major practical importance in manufacturing where operators still perform lots of manual tasks. Furthermore, taking an embodied cognition perspective, may offer additional aspects to consider for interruption research, both in how and when to make interruptions as well as how to decrease the negative impact on task performance when switching back and forth between the primary and the secondary task.

Instead of identifying the perfect points at which to interrupt subjects this experiment wound up identifying a point at which subjects should definitely not be interrupted, and in doing so looks to have uncovered an interesting effect. More importantly, we see the importance of keeping the link between the tool/object and the user stable and solid, and the effects of the tool/object not being effectively designed to take part in the context in which they should be used. The observed effect of subjects missing interruption notifications during specific phases of work will be examined more closely in a follow up experiment, and the design guidelines presented here will be revised based on findings from that follow up experiment. Tools and methods are required to support a unified approach to ergonomics, not only for this small design aspect, but for the field of ergonomics in general. This first requires that a greater understanding of the always existing link between mind and body is spread throughout the ergonomics community, and that an understanding that tasks cannot be usefully analyzed while ignoring goals and embodied actions of the person completing those tasks. Ergonomics should thus not be split into physical ergonomics and cognitive ergonomics in most cases.

We address the need for reducing the common friction between human and technology, since much of current workspaces is designed to bend our embodied human being into an unnatural shape of interaction. Instead, we should emphasize how this interaction is enacted through bodily actions and real world experience, designing for mutual relationships between human and technology.

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